NASA Laser Risk Reduction Program

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Earth System Science and Applications Advisory Committee
Technology Subcommittee Spring 2004 Meeting
April 13, 2004, Washington, DC

Outline

- **Response to TSC observations and recommendations from November 5, 2003 meeting**
- **Results of independent peer review**
- **Description of LRRP technical content**

TSC Observations and Recommendations

- **ESSAAC Technology Subcommittee observations and recommendations from November 5, 2003 meeting:**
  - 2. NASA's technology program can greatly benefit from similar technology investments made by DOD and industry. To that end, NASA needs to form closer connections with relevant federal laboratories and with industrial labs funded by DOD.
  - 3. ESE's emphasis on active sensors, including lidars, as a major tool in the next generation of remote sensing instruments is well placed and should be accelerated. However, meeting all of the science needs in laser altimetry, wind measurements, CO_2, and ozone mapping will require a technology development program funded at substantially higher levels than current NASA laser development activities. ESE should either narrow down the scope of the applications it wishes to support or increase the funding for technology development.
  - 4. NASA should take a systems view when setting requirements for lidar by including optics, detectors and laser transmitters in the overall analysis. A similar trade-off should be considered between the use of expensive, data-intensive pulse digitization versus microlaser high PRF technology.

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TSC Observations and Recommendations

- **ESSAAC Technology Subcommittee observations and recommendations from November 5, 2003 meeting (cont.):**
  - 5. Review of The Laser Risk Reduction Program (LRRP) has raised a number of questions, including:
    - Despite the fact that hundreds of millions of dollars of laser-based sensors are at risk (CALIPSO, ICESat, etc.) LRRP does not appear to have made significant progress towards reducing the risk of laser failure, does not have clearly defined objectives and deliverables, and has little awareness of similar DOD programs and investments.
    - Although the LRRP program has a stated budget of $9 million, judging by the reported results, it appears that only a small fraction of that amount has been spent on risk reduction studies.
    - Is testing being done in realistic environments and configurations?
    - GSFC is building a 1-micron laser. It is not clear how it will be significantly different from other currently available 1-micron lasers.
    - It is recommended that NASA conduct a thorough evaluation of the program based on progress realized thus far toward improving laser reliability. NASA should consider focusing the effort on diagnostics and realistic validation of laser modules, or returning the funds to the IIP and establishing LRRP as a part of IIP.
  - 6. Greater attention should be paid to the data aspects of the various laser technologies to insure its optimal use by the science community.

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Response to TSC Points

2. NASA's technology program can greatly benefit from similar technology investments made by DOD and industry. To that end, NASA needs to form closer connections with relevant federal laboratories and with industrial labs. funded by DOD.

- NASA ESE is (and has been) actively seeking partnerships with other Federal entities with common interests; the LRRP was briefed to elements of DOD over a year ago with the intent of identifying areas of potential joint work.
- ESE co-chairs the DOD Space Technology Alliance Laser/Optical Technology Working Group, which recently held its second meeting. Through this mechanism ESE is made aware of DOD activities in this sensor technology field and also the industrial capability which DOD is fostering in order to meet their mission needs.
- ESTO and LRRP personnel have conducted several technical interchange meetings with major industrial vendors of space-based laser equipment and will do further interchanges in the future. Several areas for potential joint work were identified, including:
  - LDA test and evaluation
  - Packaging, thermal and contamination control
  - Technology transfer of NASA-developed hardware
  - Detectors
  - Fiber lasers
  - System modeling and analysis

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Publicizing LRRP

- **Since its inception the program goals and technical activities of the LRRP have been published in peer-reviewed journals and presented at numerous open conference series:**
  - **NASA Earth Science Technology Conference**
  - **International Laser Radar Conference**
  - **Coherent Laser Radar Conference**
  - **OSA Advanced Solid-State Photonics Conference**
  - **SPIE symposia (various)**
  - **IEEE Aerospace Conference**
  - **IEEE Geoscience and Remote Sensing Symposium**

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Community Forum on LDAs

- ESTO sponsored an industry/USG Community Forum on Laser Diode Arrays in Space-Based Applications March 2-3 in Arlington, Va.
- Attendance: 23 industry, 42 USG/contractors, 6 other.
- Purpose: Brief 2003 ICESat/GLAS failure to community.
- Intensify dialog between LDA vendor and user communities concerning technology development requirements for robust long-life diode arrays suitable for deployment in space.
- LDA related work conducted under LRRP briefed to attendees.
- In addition to the open discussion forum, six LDA vendors provided proprietary briefings to USG representatives in attendance.
- Meeting engendered robust debate between USG and industry concerning each others' needs.

NASA will proceed with establishment of a National working group composed of government/industry/academia to continue the dialog.

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Response to TSC Points (cont.)

3. ESE's emphasis on active sensors, including lidars, as a major tool in the next generation of remote sensing instruments is well placed and should be accelerated. However, meeting all of the science needs in laser altimetry, wind measurements, CO_2, and ozone mapping will require a technology development program funded at substantially higher levels than current NASA laser development activities. ESE should either narrow down the scope of the applications it wishes to support or increase the funding for technology development.

- The Earth science measurement applications targeted by the LRRP were deliberately selected to maximize return on investment by restricting effort to the development of *two primary laser sources* and by addressing the *technology challenges that are common to both*.

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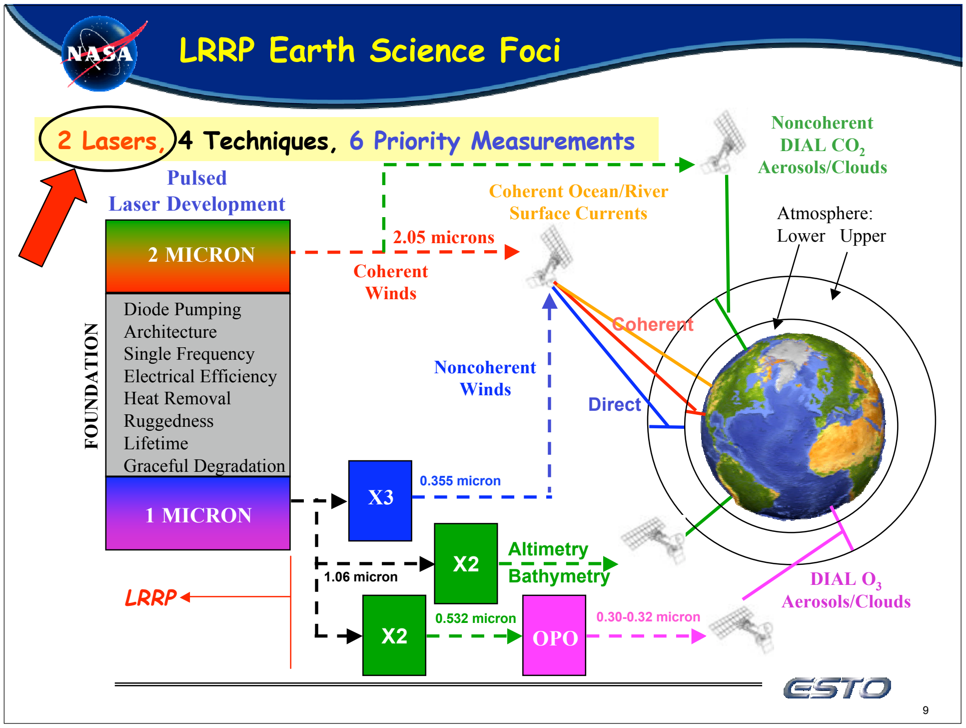
LRRP Earth Science Foci
2 Lasers, 4 Techniques, 6 Priority Measurements
Pulsed
Laser Development
2 MICRON
Diode Pumping
Architecture
Single Frequency
Electrical Efficiency
Heat Removal
Ruggedness
Lifetime
Graceful Degradation
1 MICRON
FOUNDATION
LRRP
2.05 microns
Coherent
Winds
Coherent Ocean/River
Surface Currents
Noncoherent
DIAL CO_2
Aerosols/Clouds
Atmosphere:
Lower Upper
Coherent
Direct
Noncoherent
Winds
X3
0.355 micron
X2
1.06 micron
Altimetry
Bathymetry
X2
0.532 micron
OPO
0.30-0.32 micron
DIAL O_3
Aerosols/Clouds
ESTO
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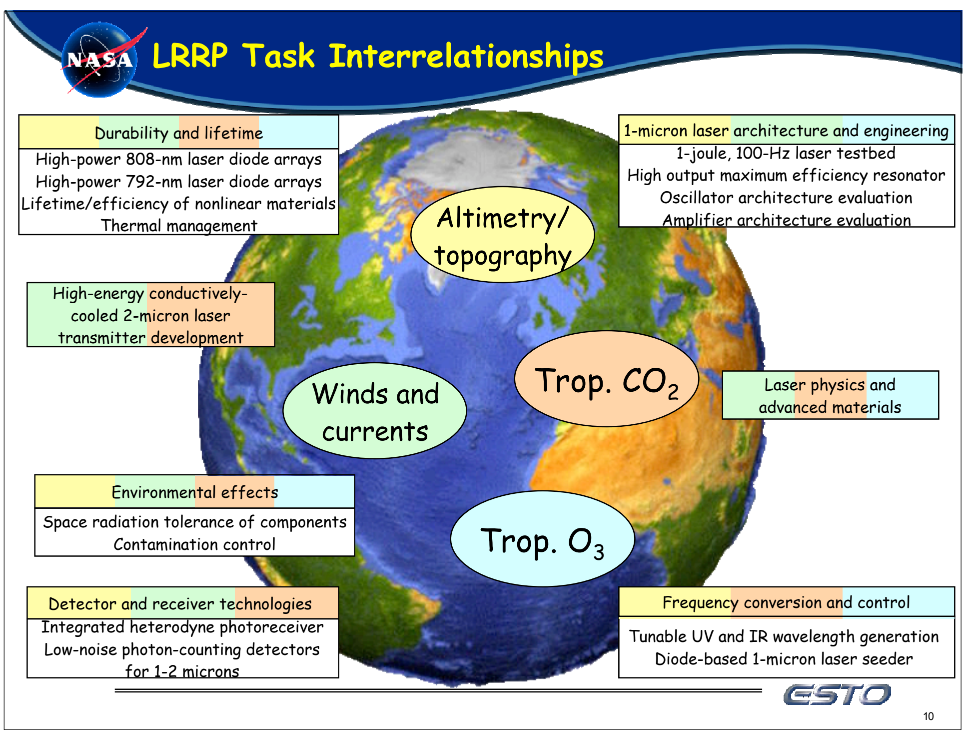
LRRP Task Interrelationships
Durability and lifetime
High-power 808-nm laser diode arrays
High-power 792-nm laser diode arrays
Lifetime/efficiency of nonlinear materials
Thermal management
1-micron laser architecture and engineering
1-joule, 100-Hz laser testbed
High output maximum efficiency resonator
Oscillator architecture evaluation
Amplifier architecture evaluation
Altimetry/
topography
High-energy conductively-
cooled 2-micron laser
transmitter development
Winds and
currents
Trop. CO_2
Laser physics and
advanced materials
Environmental effects
Space radiation tolerance of components
Contamination control
Trop. O_3
Detector and receiver technologies
Integrated heterodyne photoreceiver
Low-noise photon-counting detectors
for 1-2 microns
Frequency conversion and control
Tunable UV and IR wavelength generation
Diode-based 1-micron laser seeder
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Response to TSC Points (cont.)

4a. NASA should take a systems view when setting requirements for lidar by including optics, detectors and laser transmitters in the overall analysis.

- Mission development processes typically follow just such a strategy and are not unnaturally driven by the perceived maturity of particular subsystems.
- Language contained in the 2000 Earth Science Independent Laser Review Panel Report specifically highlighted transmitter class lasers as needy of accelerated development.
- While this is the *emphasis* of LRRP, the program does not ignore ancillary technologies. For example, significant gains are being made in the areas of detector technology under the program's cognizance.

4b. A similar trade-off should be considered between the use of expensive, data-intensive pulse digitization versus microlaser high PRF technology.

- The emergence of high-PRF microlaser approaches is of great interest to ESE because of their potential to reduce demand on laser performance, and these trades are indeed considered for some applications. However, some implementations may require technology advances in other areas. For instance, we acknowledge that single-photon-counting altimetry (a development supported by ESTO) offers significant advantages in physical accommodation requirements and instrument complexity, but some studies indicate that these attributes are attained at the cost of a dramatically increased need for onboard real-time processing capability.

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Response to TSC Points (cont.)

5a. Review of the LRRP has raised a number of questions, including:

- Despite the fact that hundreds of millions of dollars of laser-based sensors are at risk (CALIPSO, ICESat, etc.) LRRP does not appear to have made significant progress towards reducing the risk of laser failure, does not have clearly defined objectives and deliverables, and has little awareness of similar DOD programs and investments.
- Although the LRRP program has a stated budget of $9 million, judging by the reported results, it appears that only a small fraction of that amount has been spent on risk reduction studies.
- Is testing being done in realistic environments and configurations?
- GSFC is building a 1-micron laser. It is not clear how it will be significantly different from other currently available 1-micron lasers.
- It is recommended that NASA conduct a thorough evaluation of the program based on progress realized thus far toward improving laser reliability.

- Both the LaRC and GSFC portions of the program have since undergone independent peer review to assess progress, focus, direction, and relationship to work being conducted outside NASA.

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Response to TSC Points (cont.)

5b. NASA should consider focusing the effort on diagnostics and realistic validation of laser modules, or returning the funds to the IIP and establishing LRRP as a part of IIP.

- The future of LRRP was already under review before the Nov. '03 TSC mtg.
- Re-integration with IIP in FY05 has been discussed.
- Strategy for LRRP will be determined thru discussions within ESE, taking into account the findings of the two independent review panels.

6. Greater attention should be paid to the data aspects of the various laser technologies to insure its optimal use by the science community.

- Strictly speaking this activity is an integral part of the mission planning process and is outside the scope of the LRRP. However, the response to 4b above is indicative of the sorts of trades which need to be performed to address this particular question.

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Results of independent peer review

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Peer Review Conclusions

- **LaRC LRRP Technology External Peer Review Panel Findings (S. Alejandro, AFRL, Chair):**
  - The panel views the LRRP as critical to the successful development of lidar as a scientific tool for NASA science missions. There is significant NASA-specific laser development required that will not be done in the absence of NASA funding.
  - The LRRP efforts are not being conducted in ivory tower isolation from the broader activities in similar areas worldwide. The LRRP team clearly benefits from extensive outside professional connectivity that it maintains through its individual members. This has ensured that outside work has been considered in the planning and execution of the LRRP activities and has ensured that these activities are not duplicative of work already accomplished by others. The LRRP has an impressive list of partnerships and collaborations with industry, academia, and government.

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Peer Review Conclusions

- **LaRC LRRP Technology External Peer Review Panel Findings (cont.):**
  - LRRP [is] well organized and the specific activities and levels of effort to be well matched to the available resources (funding and people). *The exceptions to this were in lidar and laser performance modeling and simulations, improved 2-micron detectors, and diode laser lifetime testing efforts, where it seemed progress was being restrained by a lack of resources*. While all the other areas of work could benefit from increased funding, they were considered to be currently funded adequately to the level required to ensure they would make progress towards achieving their goals.
  - No overarching LRRP roadmap and program plan was presented to the Panel. Having a clear quantitative program plan and roadmap would allow the LRRP to effectively defend its existence and funding, and it should also enable better assessment of progress.

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Peer Review Conclusions

- **LaRC LRRP Technology External Peer Review Panel Recommendations:**
  - LRRP create a consolidated program plan and roadmap, which include for all efforts: the user/mission supported, quantitative and qualitative objectives for each effort, technology challenges that provide the focus for each effort, milestones, technology transition/insertion against a timeline, and the benefits and payoffs of a successful effort.
  - Additional funding be considered to accelerate the work in the areas of diode laser lifetime testing, improved detectors, and modeling and simulation capabilities.
  - Each effort should clearly identify the specific earth science or other mission(s) that are being supported and laser requirements for the mission.

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Peer Review Conclusions

- **LaRC LRRP Technology External Peer Review Panel Recommendations (cont.):**
  - Need to clarify prioritization of efforts. LRRP as presented to the Panel gave no indication of which effort was more important than another. Ideally, both science payback from a prospective mission and state of technology would be considered in establishing LRRP priorities. A dialogue with NASA headquarters would be helpful here. The next stage of the effort might require focusing on fewer high impact areas, and the LaRC LRRP would be well-served to be able to articulate its priorities.
  - Each effort needs to better articulate the payoff(s) to be gained by success. A good example was provided by the Integrated Heterodyne Photoreceiver presentation where it was shown that a successful 3dB improvement in sensitivity could potentially payoff in a savings of 125kg in weight and 600W in power.

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Peer Review Conclusions

- **LaRC LRRP Technology External Peer Review Panel Recommendations (cont.):**
  - Radiation hardness testing at the material, component, and device levels should be considered earlier in the efforts. It appeared such testing was generally not being formally considered other than being acknowledged as something that needed to be done at some later date. Such testing is not necessarily difficult to do and could indicate problem areas that could prove significant and warrant a serious level of effort in the future to address. Early detection of radiation-susceptible materials could save wasted time and effort in a long-term development program.
  - There was no indication that Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) contracts were being used as part of the LRRP effort. If not, their use might be considered as a means to further leverage the LRRP efforts.
  - LRRP needs to clarify the priority of water vapor measurements from space with respect to the other earth science missions. Although this was presented to the Panel, laser technology associated with water vapor DIAL measurements was not presented as a LRRP mission of record. Given the concentration of water vapor lidar interests overall, there is ample expertise available to clarify this issue for NASA.

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Peer Review Conclusions (cont.)

- ***GSFC LRRP Technology External Peer Review Panel Findings and Recommendations (T. Y. Fan, MIT/LL, Chair):***
  - **The LRRP is critical if NASA is to develop lidars as tools for science missions**
    - NASA space-based lidar transmitters have a unique set of drivers (efficiency, operating lifetime, environment) that will not be addressed by other laser development efforts
    - These technology efforts underpin large system programs
  - **Recommendations**
    - Continue LRRP and add resources
    - Work toward a continuation beyond FY06
  - **The Program is generally working on the right problems, but priorities need to be set and better focus is needed on addressing key risks**
    - The program is addressing issues in 1-μm transmitters, lifetime, and nonlinear frequency conversion, which are all important to reduce risk
    - No clear priorities for program elements were articulated
    - Some of the program elements do not effectively address the terms of the LRRP Project Agreement (no articulation of TRL levels)
  - **Recommendations**
    - LRRP management should develop a set of priorities and restructure efforts to reflect priorities, if needed
    - Review program elements to see whether they address key risks
      - Alternative seeder, damage theory
    - Improve program planning
      - Schedules, payoffs, risks retired, TRL improvements need to be better articulated

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Peer Review Conclusions (cont.)

- **GSFC LRRP Technology External Peer Review Panel Findings and Recommendations (cont.):**
  - **Some program elements have inadequate resources, and adjustments ought to be made to free resources**
    - Financial resources can be freed by terminating or reducing level of effort on some elements
    - Freed financial resources can be used to bolster efforts in some elements or address risks that are not currently funded
  - **Recommendations**
    - Discontinue alternative seeder, damage-theory, and thermal-control elements
      - Seeding is important for breadboard, but alternative seeder component development does not address a key risk
      - Damage theory appears not be on firm scientific ground and is not producing useful outputs to LRRP
      - LRRP resources are inadequate to advance thermal control (much greater resources being applied to this area by the DoD)
    - Adjust level of effort on photodiode element
      - Potential for large leverage and appropriate for LRRP but funding is inadequate to make a difference (large investments currently by DoD)
    - Consider reducing level of effort on laser breadboard by downscaling energy per pulse goal
      - Reducing risk of slab technology should be possible by 1/4 – 1/2 scale energy per pulse (keep fluences the same)

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Peer Review Conclusions (cont.)

- **GSFC LRRP Technology External Peer Review Panel Findings and Recommendations (cont.):**
  - **Improved outreach is needed to gather information, leverage off of activities in other organizations, and to disseminate the findings of the LRRP**
    - Significant information exists in the larger community that would help the LRRP in areas such as damage, space-based lasers, diode-array lifetime, and contamination control
    - Need to have clearer coordination in LaRC in areas of overlap (nonlinear conversion, diode lifetime)
    - Talent exists in other organizations to help with LRRP issues
    - The LRRP needs to disseminate its findings to better serve as a national resource
  - **Recommendations**
    - Increase efforts to gather information from outside GSFC
    - Set up regular coordination meetings with LaRC
    - Identify best external people/organizations that can help LRRP
    - Consider holding a workshop (perhaps in conjunction with LaRC) to disseminate findings
    - Develop and implement a process to include industry, academia, and other government organizations to share information

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Peer Review Conclusions (cont.)

- **GSFC LRRP Technology External Peer Review Panel Findings and Recommendations (cont.):**
  - **More upfront analysis is needed to vet proposed program elements for ultimate flight use and quantify risks**
    - Phase conjugation element did not appear to provide a path to space
    - Compressor thermal control appeared to be too power consumptive
    - Nonlinear-crystal thermal loading is considered to be a risk issue but no quantitative analysis of the problem or proposed solution was presented
    - No analysis of whether seeder frequency-stability goals could be reached using current approach
  - **Recommendations**
    - Vet elements more strongly to determine applicability of proposed solutions
    - Perform more analysis to quantify risks
    - Assess path-to-flight for key elements and technologies
  - **Program elements need to produce more generally applicable findings**
    - Choice of laser breadboard architecture is too GSFC specific
    - Some of the findings do not provide sufficiently general engineering guidance (e. g., effect of cylindrical lens focusing on damage)
  - **Recommendations**
    - Recast experiments to provide more general engineering guidance
      - For example, determine what truly sets the design envelope for slabs
      - Perform key conversion efficiency and thermal analysis for nonlinear conversion

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Peer Review Conclusions (cont.)

- **GSFC LRRP Technology External Peer Review Panel Findings and Recommendations (cont.):**
  - **The diode-array lifetime and characterization element should serve as a model for the nonlinear crystal lifetime and contamination elements**
    - The diode-array element was found to be executed in a superior fashion
  - **Recommendations**
    - Test plans and protocols need to be drafted for nonlinear crystal and contamination testing
    - Nonlinear crystal testing should focus on doing a few materials well, as opposed to a larger survey of materials

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LRRP Technical Description

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LRRP Foundation Elements

- **High-power diode laser pump arrays**
  - Develop, scale, and qualify long-lived, space-compatible laser diode arrays with current vendors
  - Evaluate currently available laser diode arrays for performance, life and configuration required for future space-based laser missions
- **Space radiation tolerance of critical laser components**
  - Radiation damage impact on optical component performance
- **Lifetime and efficiency of nonlinear materials**
  - Lifetime tests of frequency conversion materials in high-fluence operation; identification of failure mechanisms and deterioration processes
- **Optics cleaning/contamination**
  - Determine tolerance levels and develop contamination/cleaning protocols for high-fluence operation of bulk and coating materials
- **Oscillator/amplifier architectures**
  - Space qualifiable laser designs resistant to self-inflicted optical damage and operable in space for 2 billion shots or more
- **Thermal control**
  - Develop robust techniques for waste heat management in space-based laser systems

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LRRP Application Specific Elements

- **Nonlinear optics research for space-based DIAL**
  - Materials and architectures for tunable, robust narrowline UV/IR laser transmitters
- **Diode laser-based seeder**
  - Low part-count, robust substitute for conventional 1-µm seeder laser architectures currently in use
- **2-micron laser transmitter**
  - Demonstrate technologies applicable to all conductively-cooled, high-power diode-pumped 2-micron laser transmitters
- **Receiver technologies**
  - Develop integrated heterodyne receiver for improved coherent 2-µm lidar system efficiency
  - Develop improved quantum efficiency photon-counting detectors at 1-2 µm
- **Laser physics and advanced materials research**
  - Develop line tunable diode-pumped Nd laser pumps for nonlinear generation schemes
  - Develop narrowband, long pulse, low average power pump laser for wavelength control

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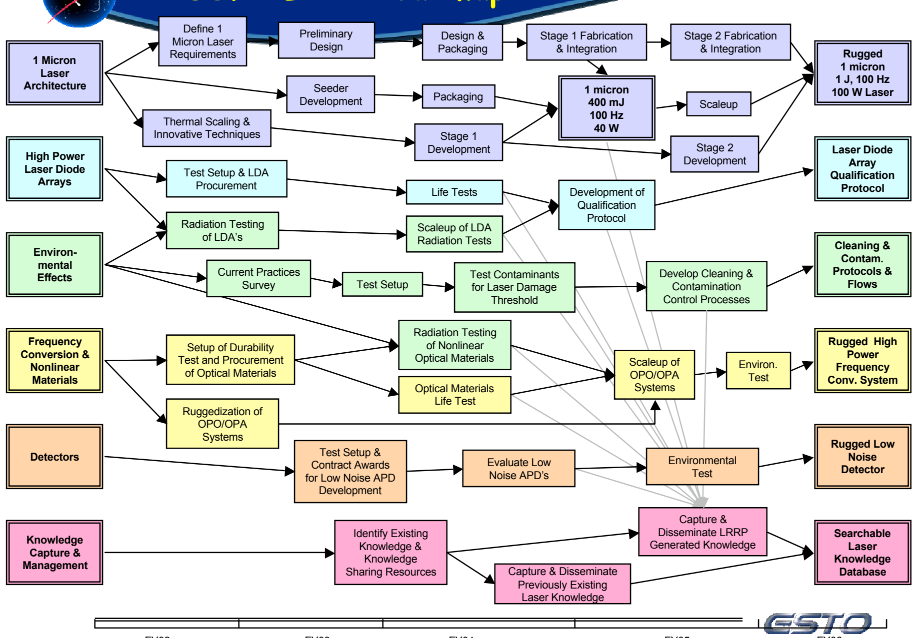
GSFC LRRP Roadmap



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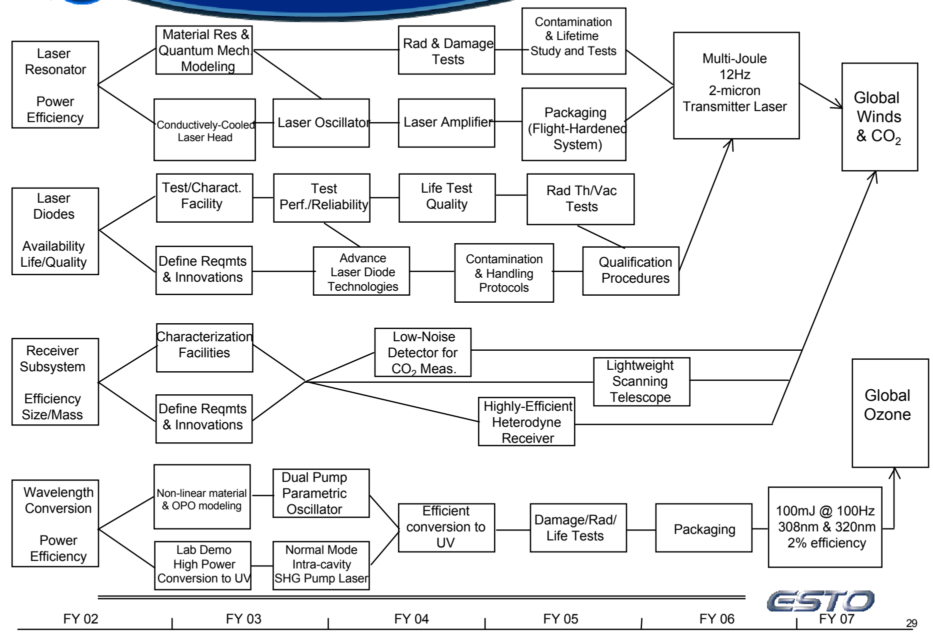
LaRC LRRP Roadmap



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2-Micron Pulsed Transmitter Laser

258-80-058

Jirong Yu, NASA LaRC

Objective

- Develop and demonstrate technologies leading to a conductively-cooled, diode-pumped 2-micron laser for space-based lidar applications.
- Address major laser development issues:
  - energy; efficiency; beam quality; conductively cooled laser thermal management; optical damage and operational life time

Accomplishments

- Successfully demonstrated for the first time, Ho,Tm:LuLF laser system with 1050-mJ Q-switched output energy. This was accomplished using one power oscillator and two amplifiers operating in double pulse mode. In the last 10 years, LaRC has advanced the energy from 20 mJ to 1 J.
- Successfully advanced the laser head design and manufacture technology. The laser head had progressed from liquid cooled to partially liquid cooled to monolithic partially liquid cooled and in parallel, fully conductively cooled development stages.
- Significant progress towards the demonstration of the first conductive cooled laser has been made. For performance characterization, thermal feedback and diagnostics of the oscillator were designed and incorporated.

Schedule and Deliverables

- Complete evaluation of a fully conductive cooled oscillator performance (4/04).
- Validate Ho,Tm:LuLF laser transmitter in ground test (6/04).
- Thermo-optical/mechanical analysis of fully conductive cooled amplifier (8/04).
- Demonstrate 1.5-J partial conductive cooled laser (9/04)
- Complete design of fully conductive cooled amplifier; demo 1.5-J partially cond. cooled laser system (12/04).

Projected Infusion

Coherent Doppler winds and carbon dioxide measurement.

TRL$_{Current}$ = 4

Instruments | Active Optical | FY04: $ 2305K

ESTO

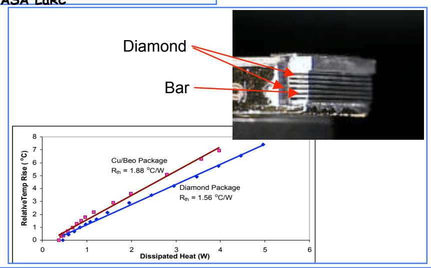
Pump Laser Diode Advancement and Validation

258-80-059

Farzin Amzajerdian, NASA LaRC

Objective

- Develop state-of-the-art characterization and life-time test facility and address 792-nm laser diode issues:
  - Limited reliability and lifetime
  - Lack of statistical and analytical bases for performance and lifetime prediction
  - Limited commercial availability
- Develop advanced laser diode array (LDA) architectures with improved efficiency and thermal characteristics



Accomplishments

The Laser Diode Characterization/Lifetime Test Facility comprises two measurement stations: Laser Diode Characterization Station and Lifetime Test Station. The assembly of the Characterization Station has been completed and over 60 LDAs have been characterized.
Fabricated and tested an advanced LDA package utilizing Diamond substrate and heatsink. Demonstrated 17% reduction in thermal resistance that can translate to increased lifetime and reliability.

Schedule and Deliverables

- Initiate lifetime testing (2/04).
- Expand lifetime test station to measure 12 LDAs simultaneously (4/04).
- Modify G package for better thermal properties (8/04).
- Fabricate and characterize advanced composite substrate materials (9/04).

Projected Infusion

Coherent Doppler winds and carbon dioxide measurement.

TRL $_{Current}$ = 4

Instruments | Active Optical | FY04: $ 635K

ESTO

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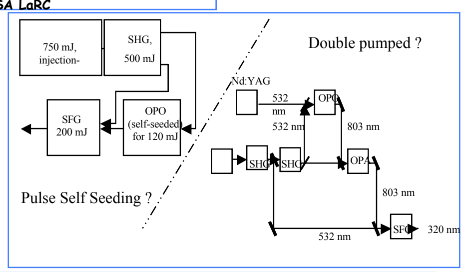
UV Wavelength Conversion Technologies from 1 Micron

258-80-060

Upendra Singh, NASA LaRC

Objective

- Develop efficient 1-micron to UV wavelength conversion technology to provide tunable, pulsed UV source capable of space-based operation in future NASA missions including Differential Absorption Lidar (DIAL) measurement of O_3.



Approach

- Evaluate the OPO/SFG designs with the objective of demonstrating 200 mJ @ 308 nm and 320 nm with 1 micron to UV efficiency of 15-20 %.

Schedule and Deliverables

- Demonstrate highest possible depletion of pump-beam energy in RISTRA OPO using technique of pulsed self-seeding (1/04).
- Integrate RISTRA with 1-micron pump to achieve 40 mJ of 320 nm at 50Hz (9/04).

Co-I's/Partners

Collaborator: DOE Sandia National Lab.

Projected Infusion

Ozone measurement.

TRL $_{Current}$ = 3

Instruments | Active Optical | FY04: $ 400K

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Laser Physics, Quantum Mechanical Models, and Materials Research

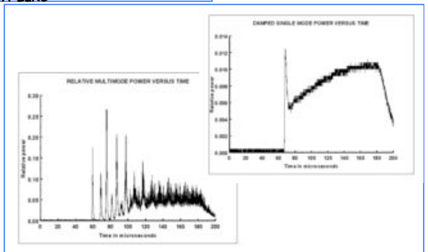
258-80-62

Norman Barnes, NASA LaRC

Objective

Develop a simple, line tunable laser system based on diode pumped Nd laser technology for lidar applications in the ultraviolet such as ozone and sulfur dioxide.

Develop a narrow spectral bandwidth, long pulse length, low average power pump laser for wavelength control of lidar systems.



Accomplishments

Damping of relaxation oscillations in a unidirectional Nd:YAG ring oscillator demonstrated:

- -Narrow linewidth
- -Second harmonic operation
- -20% conversion efficiency achieved

A single laser oscillator demonstrated synchronous Q-switched pulses at 1.064 and 1.319 μm. With the dispersive resonator, other wavelength combinations could be produced as well. Because the same mirror and laser rod are used for both wavelengths, the pulses are collinear as well. Synchronism and collinearity were demonstrated by mixing the two wavelengths to produce 0.589 μm.

Schedule and Deliverables

- Optimize second harmonic conversion, >40% (2/04)
- Increase gain of dual wavelength laser, >5 (4/04)
- Optimized sum frequency mixing (6/04)
- Relaxation oscillation suppressed oscillator, 10mW peak (8/04)
- UV generation at 300-320 nm (9/04)

Projected Infusion

Ozone measurement.

TRL $_{Current}$ = 3

Instruments | Active Optical | FY04: $ 220K

ESTO

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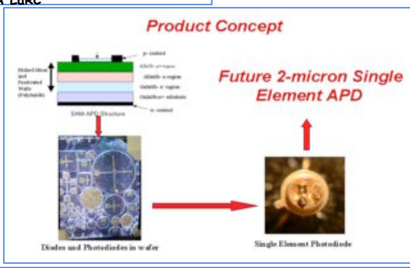
2-micron Detector Development

258-80-085

Nurul Abedin, NASA LaRC

Objective

Develop, test, and implement new technology 2-µm detectors for noncoherent-detection laser remote sensing applications from ground, aircraft, and space.



Accomplishments

•Completed 34 existing 2-μm detectors characterization.
• Completed recent developed 62 InGaSb samples from wafer 5 and 54 InGaSb samples from wafer 3.
• Performed spectral responsivity calibration at different temperatures and bias voltages, NEP, detectivity (D*), I-V & C-V measurements, and surface topography using Atomic Force Microscope.

Schedule and Deliverables

- Materials growth using liquid phase epitaxy and characterization (5/04).
- Epitaxial growth by using improved Metal-Organic Chemical Vapor Deposition (MOCVD) system (6/04).
- Complete single element APD detector fabrication and characterization (9/04).
- Single avalanche photodiode (APD) with sensitivity >50 A/W @ 2.05 microns, collecting area 300-500 microns, NEP <2x10-14 W/√Hz, and QE 80% @ 2.05 microns (10/04).

Projected Infusion

High-resolution carbon dioxide profiling.

TRL $_{Current}$ = 3

Instruments | Active Optical | FY04: $ 150K

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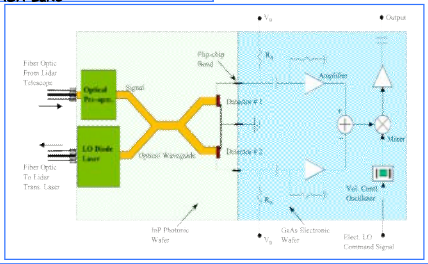
Integrated Lidar Photoreceiver

258-80-086

Farzin Amzajerdian, NASA LaRC



Objective

Develop Integrated Heterodyne Photoreceiver (IHP) packaging and demonstrate:
-Improved Coherent Lidar system efficiency by 3dB
-Reduced required local oscillator power about 80%
-Improved robustness

Accomplishments

- Fabricated 5 integrated fiber-coupled detector/amplifier devices using dual balanced detectors technique.
- Fabricated a number of miniature lidar receiver boards with detectors and gold tracks.
- Completed design of a custom GaAs MESFET amplifier matching detector parameters for optimum receiver operation.

Schedule and Deliverables

- Fabricate and characterize packaged MCM receivers with 1-GHz and 5-GHz bandwidths (6/04).
- Fabricate and evaluate phototransistor receiver (7/04).
- Demonstrate optimum receiver performance (2.5-dB improvement) (9/04).
- Validate receiver performance in subsystem (12/04).

Projected Infusion

High-resolution wind and carbon dioxide profiling.

$TRL_{Current}$ = 3

Instruments | Active Optical | FY04: $ 290K

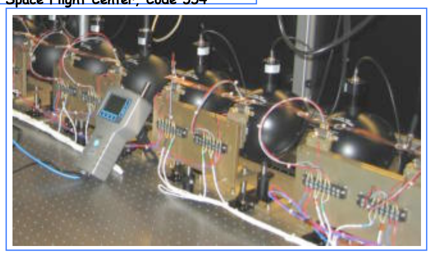
ESTO

35

High-Power Laser Diode Arrays

258-80-041

Mark Stephen, NASA Goddard Space Flight Center, Code 554



Objective

- Quantify effect of operational and environmental parameters on Laser Diode Array (LDA) performance.
- Develop procedures for purchasing, handling, storage and operation.
- Develop prediction/screening capability.
- Enable improved reliability and performance of future laser missions.

Approach

- Fully characterize the LDAs to establish a baseline for individual array performance and status.
- Subject LDAs to stress by exposure to defined environment
- Characterize LDAs to gauge effect of the stressor.

Schedule and Deliverables

Q1-Q4/04: Upgrade characterization/measurement capability.

Q1-Q4/04: Continue first performance test (Temperature & Power cycling).

Perform Radiation Tests on LDAs (6/04).

Begin second performance test (# of bars / array, 2 vendors) (6/04).

Co-I's/Partners

- Applied Physics Lab (APL)
- Coherent Photonics Group
- Cutting Edge Optronics (CEO)

Applicability

Direct detection Doppler winds, altimetry, ozone measurement.

TRL_{In} = 4

Instruments | Active Optical | FY04: $ 400K

ESTO

36

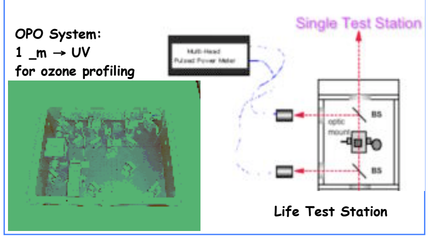
Frequency Conversion and Nonlinear Materials

258-80-044

Hossin Abdeldayem, NASA Goddard Space flight Center, Code 554

Objective

- Develop and demonstrate efficient non-linear optical technologies for the conversion of 1-micron pump laser light into alternate wavelengths required for various LIDAR measurements.
  - Tunable IR range for profiling CO_2
  - Tunable, narrow band UV range for profiling ozone.
- Investigate the reliability and durability of nonlinear optical materials used in frequency conversion and in laser oscillator technologies.



Approach

- Apply optical parametric conversion techniques to downshift 1-micron radiation into the 1.57-micron CO_2 sounding band.
- Develop OPO UV modules for converting 1 micron light into UV frequencies for ozone profiling.
- Conduct life tests of critical optical materials used in OPO and Q-switch technologies.

Schedule and Deliverables

- Packaged 1-kHz OPO/OPA generating 305 nm output from 100 mJ, 1 micron pump (4/04).
- Begin lifetest of selected OPO materials (5/04).
- Breadboard narrowband, tunable OPO/OPA system (6/04).
- Breadboard of 320 nm 1-kHz OPO/OPA (9/04).
- Life test results for selected OPO materials (9/04).

Co-I's/Partners

- Tom McGee, GSFC 916
- John Burris, GSFC 916
- ITT Industries
- Ed Dowdye, GSFC 554
- Jerry Blevins, SSAI

Applicability

Tropospheric CO_2 and ozone.

TRL_{In} = 2,3,4

Instruments | Active Optical | FY04: $ 800K

ESTO

37

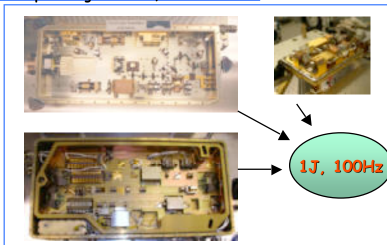
1-Micron Laser Architecture

258-80-078

Anne-Marie Novo-Gradac, NASA Goddard Space Flight Center, Code 554

Objective

- Develop and demonstrate technologies leading to a diode-pumped 1-micron, 1 Joule 100 Hz laser for space-based lidar applications.
  - 100 mJ oscillator
  - Three optical amplifier stages.
  - Frequency stabilized 1064 nm laser seeder unit.
  - Thermal management technologies to dissipate the large amount of waste energy generated.
  - Robust opto-mechanical design.
  - Robust and programmable drive electronics.



Approach

Integrate elements of the laser risk reduction program into the development of the laser using it as a test bed to identify challenges and to verify the results of addressing those challenges.

Schedule and Deliverables

- First order thermal and mechanical design for flight qualifiable packaged amplifier (4/04).
- Breadboard unit for 100 mJ oscillator (5/04).
- Complete laser seeder environmental test (6/04).
- First order design for power supplies and drive electronics for oscillator and amplifier (6/04).
- Breadboard unit for 1st optical amp. stage (9/04).

Co-I's/Partners

- Barry Coyle, GSFC 920
- Dr. R. Kay, American University
- Steve Li, GSFC 554
- Jason Budinoff/Andrea Poulin, GSFC 544
- Dan Butler/Lou Fantano, GSFC 545
- Alan Lukemire, Space Power Electronics

Collaborators: LaRC, Industry, Academia

Applicability

Direct detection Doppler winds, altimetry, ozone measurement.

TRL_{In} = 3

Instruments | Active Optical | FY04: $ 2500K

ESTO

38

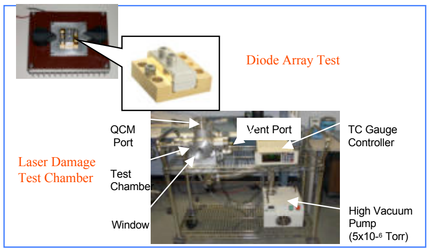
Environmental Effects on Optical Materials

258-80-079

Randy Hedgeland, NASA Goddard Space Flight Center, Code 545

Objective

- Understand mechanistic and empirical causes for damage in laser systems as a function of materials, cleaning processes, operational environments, and laser wavelength.
- Evaluate radiation tolerance of critical component technologies required for implementing laser systems in a space environment. Measure the effect of radiation on the performance of laser diodes and nonlinear optical components.



Approach

- Develop theoretical model of contamination related optical damage mechanisms and experimentally validate model.
- Determine particulate and molecular levels that induce damage in space flight lasers and compile database of results.
- Develop a compact portable instrument to measure laser diode array performance.
- Measure the effect of beta (Cobalt 60) and proton exposure on output of laser diode arrays.

Schedule and Deliverables

- Laser damage (1064 nm) measurements of optics exposed to first series of test contaminants (12/03).
- Build second diode test instrument (6/04).
- Proton testing of diodes (Indiana) (6/04).
- Radiation testing of selected OPO materials (7/04).
- Preliminary laser damage contaminant database (9/04).

Co-I's/Partners

John Canham, Swales
Christopher Scurlock, Genesis Engineering
Matthew Bevan, JHU-APL

Applicability

All flight laser systems.

TRL_{In} = 3/4

Instruments | Active Optical | FY04: $ 500K

ESTO

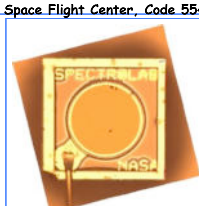
Low-Noise Photon-Counting Detectors for 1-2 Microns

258-80-082

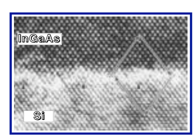
Michael Krainak, NASA Goddard Space Flight Center, Code 554

Objective

- Optical detectors with photon counting sensitivity over the 1.0 - 2.0 micron wavelength range:
  - Quantum efficiency: 10 - 70%
  - Detector size: 200 mm diameter
  - Dark counts < 100 kcps
  - Max count rate > 10 Mcps
- Solid State APD: InGaAs photocathode, silicon or InAlAs avalanche region.



Low-Noise InGaAs APD



SEM photo of InGaAs-Si interface

Approach

Most commercial InGaAs APDs are grown on indium phosphide (InP) substrates. To access improved noise performance it will be necessary to investigate alternative substrate materials. This task will procure InGaAs-Si APDs from Nova Crystals and InGaAs-InAlAs APDs from Spectrolab and conduct photon counting experiments at low temperature.

Schedule and Deliverables

1) 200 and 300 micron diameter InGaAs APDs with dark current <5 nA (11/03)
   - Present commercial (i.e. non-custom) device performance is 60 nA.
2) Photon counting test results for (1) at 77 K (9/04)
   - Desired dark counts <100 kcps,
   - Desired quantum efficiency >10%
   - Desired max count rate: >1 Mbps

Co-I's/Partners

Industrial Partners:
Nova Crystals Inc.
Spectrolab Inc.

Applicability

Altimetry, tropospheric carbon dioxide.

TRL_{In} = 2

Instruments | Active Optical | FY04: $ 100K

ESTO

Knowledge Capture and Management

258-80-084

Molly Schmitz, Science Systems and Applications Inc. (SSAI)

Objective

- Capture critical knowledge about space flight laser systems from existing and previous programs, such as mechanical drawings, work instructions, experimental results, and rosters of expert personnel.
- Identify tools that encourage knowledge sharing and collaboration between different work groups and NASA centers. Integrate these tools into the NASA laser community.
- Provide centralized location for NASA laser community to access knowledge resources.

Approach

- Capture key aspects of Laser Risk Reduction Program as well as seek out and record valuable information from previous laser programs. Integrate information into a centralized library.
- Identify existing NASA resources suitable to storing, searching, and disseminating knowledge. Input laser knowledge to these resources.
- Develop web-based portal that directs users to the various knowledge resources.

Schedule and Deliverables

- Centralized catalog of optomechanical designs for previous flight laser projects (MOLA, GLAS, etc.) (5/04).
- Centralized library of key documents from LRRP and previous laser projects (7/04).
- Web portal that directs users to these resources (7/04).
- Catalog (phonebook) of topical experts (9/04).
- Laser related "lessons learned" submitted to the NASA Lessons Learned Information System (LLIS) (9/04).

Co-I's/Partners

- A. Novo-Gradac, GSFC 554
- Edward Rogers, GSFC 300
- Andrea Poulin, GSFC 544
- James Marsh, GSFC 544
- Armando Morell, GSFC 544
- Billy Mamakos, Design Interface, Inc.

Applicability

All flight laser programs.

TRL_{In} = 2

Instruments | Active Optical | FY04: $ 200K

ESTO

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Summary of Expected Exit Points

At the end of the planned LRRP period of performance the anticipated exit accomplishments are:

1 J, 100 Hz, injection-seeded single-mode pulsed 1064-nm source; 6% WPE, 2DL

1.5 J, 10 Hz pulsed 2-micron source

100 mJ/pulse IR/UV frequency generation schemes scalable for space systems

Improved efficiency (>10% QE) photon counting detectors at 1-2 microns (dark counts <100 kcps; count rate >10 Mcps)

Procedures and protocols for cleaning and contamination control

Procedures and protocols for testing and space qualifying laser diode pump arrays

Database of material tolerances toward contamination and radiation damage

Searchable Internet-accessible knowledge repository

ESTO

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